Cost-Effective Casting Design: From Drawing

In this final installment in our series on cost-effective casting design, the conceptual framework approach to design is reviewed as well as the importance of carrying this approach through the entire process, including secondary operations. The potential of CAD/CAM for more accurately producing casting and machining drawings is also explored.

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The key to the conceptual framework approach to casting design that has been discussed in the first two parts of this series (see modern casting, Sep and Oct 1985) is its application throughout the design process—from the drawing board to finished casting.

While we have already discussed the importance of understanding the characteristics of various foundry alloys and how their shortcomings can be overcome through proper design, the same thinking can also help the designer and foundry engineer to overcome potential physical and mechanical problems in the final cast part. In addition, by developing an encompassing framework, designers can fully realize the many advantages offered by metalcasting, such as its capability of producing parts with infinitely variable shapes, reducing tooling costs as well as minimizing, and in some cases, eliminating secondary operations.

As a point of review, let’s again quickly look at one of the important characteristics of foundry alloys, slag/dross formation. As pointed out earlier, some molten metal alloys generate more slag/dross than others and are more likely to produce small globs of nonmetallic material in a casting.

Unless a specific application is exceedingly critical, a few small, rounded inclusions will not affect casting performance. In the case of critical applications, such as jet engine turbine blades, processes such as vacuum melting and pouring can be utilized and will virtually eliminate the problem of slag/dross.

In the case of diecasting, hot chamber methods force the molten metal into the die from a completely submerged position, well below any floating slag or dross. In sandcasting, gating systems are designed to take advantage of the buoyancy of nonmetallic liquids in order to trap them and prevent their entry into the mold cavity. In both sandcasting and precision casting methods, new technology in filtering molten metals has further advanced the foundry’s ability to eliminate nonmetallics in castings.

Since nonmetallics are hard metal oxides, they can create major problems for the shop floor foreman and machinist.

To minimize the chance of finding a nonmetallic inclusion in a critical machined surface, it is a good practice to design those surfaces in the lower portion of the mold (the drag), so that anything nonmetallic will float up to a higher level, away from the critical surface. An example of this practice is shown in Fig. 1.

One of the great opportunities that comes with designing castings is the ability to minimize residual stress and stress concentration. Unfortunately, this opportunity is frequently lost when the designer uses straight-line, fabrication-type thinking. We often forget that we are not restricted to mill shapes when designing castings. The example in Fig. 2 illustrates this point. This approach is sometimes called wave design, and it allows sections to bend slightly, relieving residual stress and minimizing overall distortion.

Fig. 1. To minimize the occurrence of nonmetallic inclusions appearing in critical machined surfaces of castings, it is recommended that these surfaces be designed in the drag (lower) portion of the mold, as shown here, which will allow nonmetallics to float up and away from the important surfaces.
to Finished Casting

Fig. 2. Designing parts as castings provides the opportunity to minimize residual stress and stress concentration. As illustrated in these two designs, rigid mill shapes can often be produced more effectively as a casting.

Infinitely Variable Shape

Another opportunity with casting design is the chance to improve strength-to-weight by using the variability of sections, which only the metal casting process can achieve. The concept of variable section modulus over section length (familiar to stress analysis engineers), when combined with "system-wide" consideration of the molten alloy’s solidification shrinkage, is a very powerful weapon when the goal is to reduce mass and increase cost-effectiveness.

Consider a requirement for a wall mounted bracket like the one shown in Fig. 3. Force “F” can be applied on a pivot point in a horizontal plane. The two major force positions are shown as F_x and F_y. The resultant forces at the wall are shown as the resultant bending and torsion force from F_x and F_y.

A good way to better understand the concept of variable section shape and variable section modulus (stiffness) over the length of a section is to study the force diagrams for tension, compression, shear, bending, and torsion. Usually, these diagrams will indicate where and how the section modulus can be varied to reduce stress and still save mass.

Figure 4a shows a design concept for a narrow freezing range alloy which will require risering of heavy sections (A, B, C and D) and taper from heavy sections to thin sections. Holes in the box section are to position the core and to permit removal of the core sand from the solidified casting.

Figure 4b shows a similar design concept for a wide freezing range alloy, which features as many thermally neutral sections as possible and only one riser located at “A”. Note the difference in sections, junctions and risering between Fig. 4a and 4b.

Fig. 3. This design of a cast wall mounted bracket illustrates the capability of a metal casting, versus other fabricating processes, to improve strength-to-weight ratio by putting mass exactly where it is needed.
Fig. 4a, b. Illustrated here are two designs for the same part but for different alloys. Fig. 4a is a design concept for a narrow freezing range alloy which will require risering of heavy sections and taper from heavy sections to thin sections. Fig. 4b is a similar design concept for a wide freezing range alloy. It has many thermally neutral sections and only one riser (on the center junction) will be required. Note the difference in sections, junctions and risering.

Fig. 5a, b. These drawings show the same part and alloys illustrated in Fig. 4a and b, but are redesigned to simplify pattern and die equipment.

Simplifying Tooling

Using “system-wide” thinking, there is considerable potential for reducing costs in making simple mold configurations, regardless of the casting process used. Often the cost of pattern/die equipment is significant, especially when it must be amortized over relatively few castings. Obviously, how few is few depends entirely on the type of molding process. Few in one process might be less than 100; another, less than 10,000; another, less than 100,000.

Whatever the case may be, foundry tooling—patterns, dies, core boxes, etc.—is expensive because they are all one-of-a-kind items made by highly skilled craftsmen. Designs that eliminate unnecessary complexity can save many dollars from the total project cost. Considering again Fig. 4a and 4b, how would it be possible to use system-wide thinking to simplify the tooling?

Figure 5a shows a comparable design for a narrow freezing range alloy that completely eliminates the need for cores and which has a relatively simple offset parting line. Note that the proportion of the length and width of the main body has been changed to prevent deep pockets in the mold. Although the box section (best for resisting torsion) was originally made with a core as shown in Fig. 5a, it was lost with the elimination of the core stress concentration at “A,” is avoided with curvature and risering will be required at surfaces “B,” “C,” and “D.”

The design for Fig. 4b was for a wide freezing range alloy. For the same type of alloy, Fig. 5b shows a similar redesign that eliminates cores and maintains a relatively simple parting line. The key design feature to keep in mind here is that the casting must maintain its thermally neutral sections wherever possible. This is critical to minimize risering on wide freezing range alloy castings.

In the case of the design shown in Fig. 4b, the torsion-resisting advantage of the box section was lost because the main body core was eliminated. To minimize stress concentration from torsion at “A,” generous curvature has been provided in the redesign (Fig. 5b).

The core inside the ball tip has also been eliminated in favor of a spherical “X” section which will support socket rotation and still eliminate mass. This section can be molded without the use of a core. The only riser required will be on surface “B.” This is the consequence of thermally equal design at junctions.
away from surface "B." Only the molten casting process will allow such variability in shape, asymmetry and reduction in mass while cutting costs.

Design and Secondary Operations

As stated in Step 5 of our Casting Design Conceptual Framework, system-wide thinking must also include the secondary operations that a casting will undergo. Secondary operations might include a variety of processes such as machining, welding/joinder, heat treating, painting and plating. Each one of these has a significant effect on the casting design and must be considered at the conceptual stages of the casting design. Since nearly every casting is machined in some fashion, it is important enough to deserve special comment.

Machining is extremely critical because it involves fixtureing the casting. Usually, machining and fixtureing are the responsibility of the manufacturing engineer. These engineers typically work in different departments than the design engineers, so more than a little effort is required to include them in the conceptual stages of design. However, this step is critical.

If the designer has our Casting Design Conceptual Framework in hand and a knowledge of the four important physical properties of the alloy, he or she knows the likely surfaces for riser contacts, gate contacts and parting lines. The manufacturing engineer and the design engineer can then debate about fixture design and target/clamp locations.

The location of these fixture targets (buttons and stops) should then be indicated on the final casting drawing. This information is critical to the foundry engineer, who, with this information, can either avoid those surfaces with parting lines, risers and gates or voice his concern about them before the pattern or die is made.

Doing this properly is system-wide thinking at its cost-effective best. Furthermore, there is nothing more critical to successful CNC machining of castings than dimensionally consistent fixtureing targets.

Casting Drawings

An important part of cost-effective casting design is a mechanical drawing system that communicates the system-wide design effort to the patternemaker and the foundryman. A lot of very good, creative design and secondary operation details can be wasted if the drawings don't communicate the thought process behind the casting design.

Generally, it is best to have separate casting and machining drawings. Since so many features in a good casting design need to be expressed on the drawing, it is best to leave the machining information to a second drawing for the sake of simplicity and readability. Because the foundryman and the patternmaker need to know how the casting will be fixtured, a datum target system such as shown in Fig. 6 (or ANSI Y14.3) is highly recommended. This information is invaluable in helping the foundryman properly locate gate and riser contacts on the casting. It also forces the design and tooling engineers to give these contact surfaces consideration before finalizing the design.

The use of CAD/CAM software for producing casting designs and drawings is expected to develop rapidly and will no doubt eventually dominate as the preferred way to conceptualize and finalise casting designs.

Although CAD systems exist that can redraw (to exact scale) using a specified patternmaker's shrink factor, the art of applying patternmaker's shrink cannot be applied uniformly to all of the dimensions of a pattern in the same way.

The application of the patternmaker's solid shrink to various dimensions is not readily predictable because the shrink factor is not predictable. The patternmaker looks at prints of finished casting dimensions and machined dimensions and then applies a good deal of judgment to the amount of shrink to use on each dimension when building the pattern or die. How much a dimension will shrink depends on the type of dimension it is, especially when cores or mold wall restrictions are involved.

![Diagram of Datum Planes and Targets](image)

**Fig. 6.** The information provided in a datum target system, like the one shown here, is invaluable in helping the foundry engineer properly locate gate and riser contacts on the casting.

(Source: Steel Castings Handbook, 5th Edition)
It will be a challenge to incorporate all of these factors into a casting design CAD software package. Probably the only way to do this will be to include the pattern/diemaker in the final stages of CAD. With the pattern/diemaker at the CAD terminal alongside the designer, the two of them could resolve the best-guess shrink rates to apply to each major group of dimensions. The system could then redraw the component based on their shared judgment, and the tape or disk output of the system could then be used in CAM at the pattern/diemaker shop.

Even then, perfect casting dimensions are not assured. Remember, patterns or dies only define the dimensions of liquid castings. Mother Nature determines solid casting dimensions.

Summarized in Table 1 are the patternmaker's shrinkage rules for various foundry alloys. Notice that there is significant variation in the amount of shrinkage from one alloy to another. These values are also average expected shrinkage for unrestricted mold dimensions. In other words, mold configuration or cores that would constrain the shrinkage will result in less dimensional shrinkage. Furthermore, certain combinations of dimension length and lack of restriction can result in more dimensional shrinkage.

These uncertainties can only be resolved in two ways:

- the patternmaker/diemaker's experience;
- production of a first article or sample casting to confirm that the patternmaker’s judgment did produce the desired final dimensions.

Figure 7 illustrates the variability in patternmaker’s shrink for various kinds of dimensions. Note that the rate of shrink varies with the length of the dimension as well as mold and core constraints. It is clear that applying general patternmaker's shrinkage values without considering these other factors can produce poor results.

### Casting Inroads

The rapid development of new processes as well as the integration of new advanced technologies with the age-old technology of metalcasting has created new and significant potential for producing and using cost-effective metal components. Many manufacturers, concerned with reducing costs and improving the quality of the parts they utilize in their equipment and machinery, have already begun reviewing their use of fabricated or machined parts with an eye toward converting them to castings.

Such conversions can and have resulted in significant savings. The most interesting cases are those in which substantial savings were realized by converting a casting to a fabrication/CNC machined part a few years ago and now converting that same part back to a casting in conjunction with CNC machining or even eliminating machining completely by utilizing one of the precision casting methods now available.

The key to realizing this second round of savings is in the system-wide casting design thinking that we have described in this series of articles. In summary, the system-wide approach to cost-effective metalcasting design includes the following major concepts.

- Define the boundaries of conceptual thinking to include all of the conflicting requirements. At the design stage, creative thinking can resolve conflicts and produce simpler, more elegant designs.
- Define the boundaries of conceptual thinking to include all the upstream casting/die/pattern producing people and all of the downstream machining/assembly/using/abusing casting users.
- Do your conceptual thinking with two tools: free-hand pencil and paper or a CAD system that can produce solid shapes, tapers and variable radii; and a conceptual framework that includes the four important physical properties of molten metal alloys (fluidity, solidification shrinkage, slag/dross formation and temperature).
- Look at various alternatives before pursuing one toward a final design. The cost-effective design will be the one that is creative, yet simple.

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*Fig. 7. This graph illustrates the variability in patternmaker's shrink for various kinds of dimensions. Note that the rate of shrink varies with the length of the dimension as well as mold and core constraints.*

(Source: Steel Castings Handbook, 6th Edition.)

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